

CHEST DEFLECTION IN FRONTAL IMPACT :

An Attempt of Clarification in Terms of
Limits , in Volunteer , Cadaver and
Dummy Tests .

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AN APPROPRIATE OF ELECTRICAL IN THE
LIMITS IN THE IMPACT OF THE
DYNAMIC TESTS

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Research

Abstracts of the 1984 Annual Meeting

SUMMARY

1. Influence of the type of loading on chest deflection ,
2. Volunteer , Cadaver and dummy chest deflection in static tests ,
3. Volunteer , Cadaver and dummy chest deflection in dynamic tests ,
4. Real accidents : APR investigation ,
5. Conclusions .

THORACIC DEFLECTION

Future regulations covering frontal impact will take into account thoracic deflection as one of the criteria on the Hybrid III dummy. The maximal value suggested is 3 inches, both for restraint by inflatable airbags and by belts. Now, the forces experienced by the thorax vary greatly depending on the method of restraint used.

To highlight the problems associated with measurement of thoracic deflection, a summary is given below of the results of comparative tests carried out with volunteers, cadavers, and Hybrid II and Hybrid III dummies.

COMPARISON OF DEFLECTIONS OBTAINED WITH DISK AND BELT

TESTS WITH VOLUNTEERS

For equivalent resultant forces on thorax (sum of the forces distributed on the thorax), statical tests carried out with volunteers (1) showed that deflection measured at the sternum (4th space) was higher with a disk of six inch diameter (figures 1 and 2) ; additional deflection was about 40 % as compared to a belt.

These measurements were made on the "relaxed" thorax, and can be compared with those recorded by other laboratories. Figure 3 shows that, whereas the HSRI values fall within the corridor of values defined by the APR laboratory for the same tests with disks, those reported by LOBDELL fall outside. This divergence is no doubt due to deflections measured at different points. The deflections obtained for 3 zones of the thorax (2nd, 4th and 9th space) with belts varied by about 50 % for a given force (figure 4).

More, it can be seen from figure 5 that deflection depends on whether the thorax of the volunteer is tense or relaxed at the moment of application of forces. Precise definition of the conditions of measurement on volunteers is therefore important for determination of the tolerable limits of force and deflection.

TESTS WITH HYBRID III DUMMY

Identical tests carried out with Hybrid III indicated 30 to 40 % greater deflection with the disk (figure 6), with the difference that the stiffness of the thorax of Hybrid III is much greater than in volunteers.

On the basis of these results, it is clearly tempting to suggest a deflection limit greater for airbags than for belts. Nonetheless, it should be borne in mind that although the appearance of the first rib fractures is correlated with a given maximal deflection, it is completely unjustified to give different limit values for deflection to each restraint system. It is probable, moreover, that the first rib fractures with disks would be incurred at lower forces than with belts.

The tests carried out by Daimler Benz (2) with Hybrid III show that the disk is unrepresentative of airbag retention. The mean rib deflection noted with a driver airbag was about 25 % lower than that seen with a belt, for a force of 200 daN (figure 7). These results, unlike those noted with disks, indicate under static conditions better load distribution over the thorax for airbag restraint by comparison with belt restraint. Dynamic tests at 50 km/h performed by the same team indicate that the static results should be interpreted with care, since :

- mean rib deflection with airbags (with knee bolster) was about 20 % greater than that obtained with belts,
- on the other hand, deflection at the sternum was nearly similar for the two retention systems (-7 % for airbags).

STATIC TESTS WITH BELTS

VOLUNTEERS AND CADAVERS

When the thorax was "relaxed", the maximum tolerable force experienced by the volunteers was on the order of 70 daN for a mean deflection of 30 mm at the sternum.

Under the same test conditions, the deflections obtained with cadavers at the moment of the first rib fracture range between 50 and 80 mm for forces between 150 and 230 daN. Since the test subjects presented bone characteristics in the average range, the values obtained fell within the extension of the corridor of values noted with volunteers (figure 8).

HYBRID II AND HYBRID III DUMMIES

The thoraces of these dummies are far from comparable with those of cadavers or volunteers during the same tests. The decreased thoracic stiffness of Hybrid III by comparison with Hybrid II is more realistic, but is still 2 or 3 times too stiff in these static tests by comparison with volunteers and cadavers (figure 8).

More, the sternum of Hybrid III is also very stiff and does not allow greater deflection on the path of the belt (figure 9), even though this lack of deflection symmetry is noted with volunteers and with Hybrid II, the sternum of which is much more flexible.

The modifications suggested by DB (1), which involve fitting the sternum and the more realistic clavicle of Hybrid II on Hybrid III, improve the "biofidelity" of deflections at various parts of the thorax. But these modifications alone are inadequate : greater realism calls for considerable reduction in the stiffness of the thorax of Hybrid III.

DYNAMIC TESTS WITH BELTS

TESTS WITH VOLUNTEERS

The work of S.H. Backaitis (3) allows comparison of deflections due to dynamic impacts noted with volunteers and with Hybrid III. These tests reveal :

- excessive stiffness of the thorax of Hybrid III by comparison with volunteers,
- the effect of stress in the thorax (tense or relaxed) on mean deflection values : results comparable to those of the static tests, i.e. 20 % additional deflection for the relaxed thorax,
- a very wide corridor of values for these volunteer tests relaxed thorax) where the deflection doubles as the force increases from 200 to 300 daN (figure 10), the velocity of the restraint system produced by the pendulum being 2.8 m/s.

TESTS WITH CADAVERS

These tests were carried out, of course, under more violent conditions and resulted in considerable number of rib fractures at the highest forces. These rib fractures are related to the bone condition of the cadavers. Such condition is calculated for each subject and thus can be compared to the real-world accident population (4). This parameter, known as BCF (Bone Condition Factor) has to be taken into account in the analysis of cadaver data, before any interpretation of these data (figures 11A and 11B).

A function relating the force sustained by the thorax, the thoracic deflection and the number of rib fractures was established for different subjects, i.e. for different values of B.C.F. This function can be written as follows :

$$F = k (a - BCF)^{\alpha} \cdot (DEF)^{\beta} \quad (1)$$

were, F is the resultant force perpendicular to the thorax
 BCF is the Bone Condition Factor
 DEF is the thoracic deflection

F , BCF and DEF being know, parameters k , α and β were respectively established using a regression analysis. From the same data base a second function was established, using the number of rib fractures (NRF) to the BCF and the thoracic deflection. This function can be expressed as follows :

$$(NRF) = k' (a - BCF)^{\alpha'} \cdot (DEF)^{\beta'} \quad (2)$$

Because both relations (1) and (2) were set up on the basis of data obtained from 8 tests, it should be desirable that these relations will be validated using these data from additionnal tests. However, as shown in figure 12, these relations illustrate the several parameters involved in the thoracic deflection process.

Interesting observation can be made from data plotted in this figure. It follows that for an approximately equivalent number of rib fractures, the thoracic deflection has the same magnitude whether the value of BCF. On the contrary, the necessary loads to produce this same deflection are very different respectively for cadavers (mean BCF = 0) and living people (mean BCF = -1.2).

REAL ACCIDENTS

It is known that young people involved in accidents can withstand forces of 800 daN at the shoulder without incurring rib fractures (5). This value corresponds to a resultant force perpendicular to the thorax of about 1000 to 1100 daN. This acceptable force decreases in older subjects (figure 13) and more than 50 % of subjects over 50 years of age incur rib fractures for forces at the shoulder of greater than 400 daN (i.e. about 550 daN as resultant force). It is therefore possible to categorize threshold forces as a function of age.

It can be observed from figure 12 that for this last age group, functions (1) and (2) give a predictive number of rib fractures of 1.2 with a thorax load and BCF respectively of 550 daN and -0.8.

DISCUSSION AND CONCLUSIONS

Strictly speaking, the maximal admissible deflection which could be used as a criterion should take the age of the target population into account. The mean age of killed and involved occupants in car accidents in France is of 33 years as established in 1987 by french source (SETRA), i.e. a mean BCF of -1.6. In this case, we can note for instance in figure 12 a thoracic deflection of 65 mm for 8 rib fractures and on applied force to the thorax of 1300 daN. If one would define a protection level for a higher age, i.e. a mean BCF = 0, another pair of values could be obtained : a slightly lesser deflection and mainly much lower thoracic load (of course always for 8 rib fractures).

Static and dynamic tests with Hybrid III dummy excessive stiffness of the thoracic cage, as well as poor distribution of the deflections over the thorax, principally due to an overly stiff sternum. Improvements are therefore necessary for better biofidelity.

It would then be possible to specify the maximal admissible deflection :

- by performing tests involving the Hybrid III dummy, in which real accident conditions are reproduced with thoracic tolerance near the admissible limit,
- or, by performing tests with cadavers the bone characteristics of which are known with reference to the target population, i.e. tests using the youngest subjects. Such tests can be thus duplicated by others using the Hybrid III dummy.

The maximal deflection would then be a valuable criterion for all methods of restraint.

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- (1) A. Fayon et al.
"Thorax of 3-Point Belt Wearers During a Crash", SAE 751148, Proceedings of the 19th Stapp Car Crash Conference (1975).
- (2) Egon Katz et al.
"Chest Compression Response of a Modified Hybrid III with Different Restraint Systems", SAE 872215, Proceedings of the 31th Stapp Car Crash Conference, New Orleans, 1987.
- (3) S.H. Backaitis (NHTSA) and A. St Laurent (Biokinetics and Associates Ltd),
"Chest Deflection Characteristics of Volunteers and Hybrid III Dummies", SAE 861884, Proceedings of the 30th Stapp Car Crash Conference, San Diego, (1986).
- (4) "CCMC Position on side impact protection" (annexe 4), presented at the NHTSA Hearing on Side Impact Protection", Washington D.C., 28-29 May, 1986.
- (5) J.Y. Foret-Bruno et al.
"Correlation Between Thoracic Lesions and Force Values Measured at the Shoulder of 92 Belted Occupants Involved in Real Accidents", SAE 780892, Proceedings of the 22nd Stapp Car Crash Conference, 1978.

Fig 1 QUASISTATIC LOAD PENETRATION CURVES FOR CHEST
COMPRESSION TESTS ON HUMAN VOLUNTEERS
WITH SEAT BELT

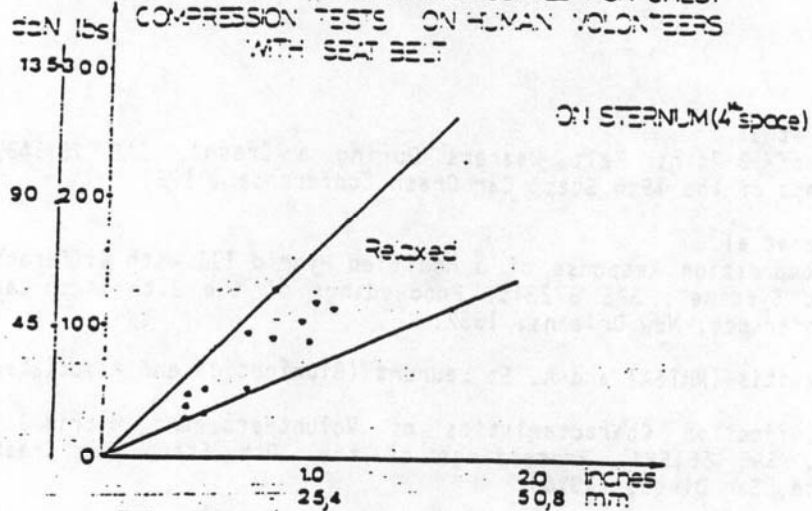


Fig 2 QUASISTATIC LOAD DEFLECTION CURVES FOR
CHEST COMPRESSION TESTS

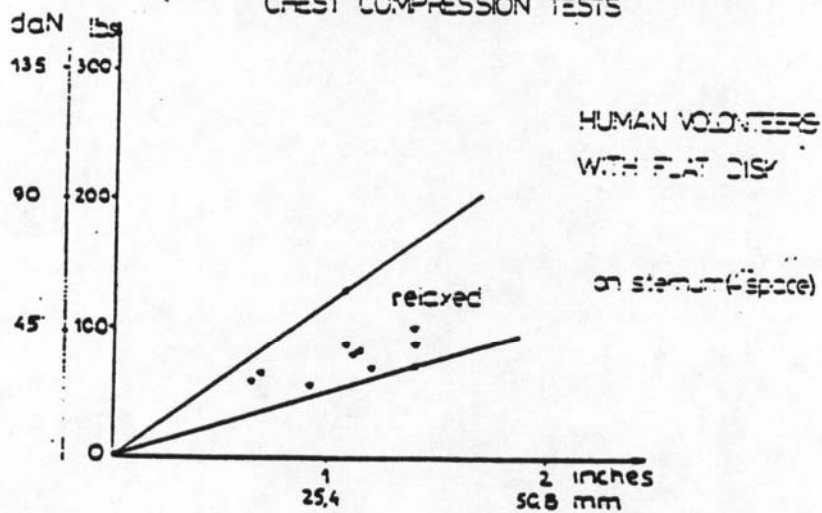


Fig 3 - QUASISTATIC CHEST COMPRESSION TESTS ON HUMAN VOLUNTEERS WITH A FLAT DISK

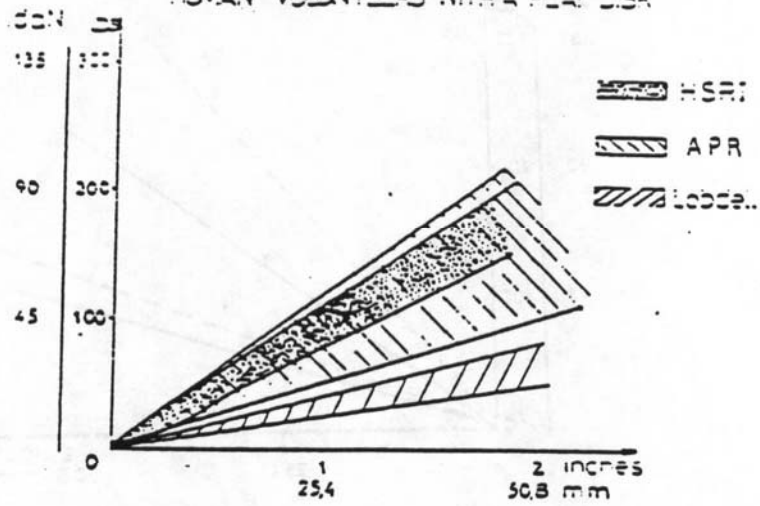


Fig 4 - QUASISTATIC LOAD-DEFLECTION CURVES FOR CHEST COMPRESSION TESTS

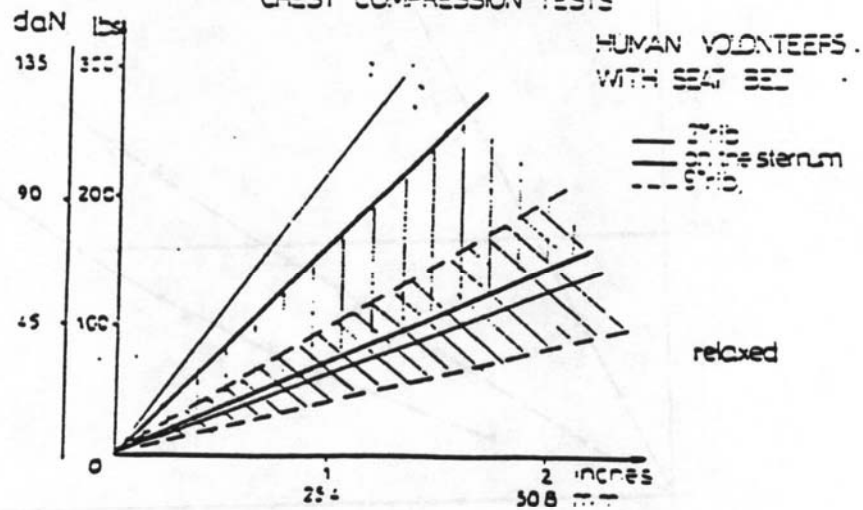


Fig 5. QUASI-STATIC LOAD DEFLECTION CURVES FOR CHEST HUMAN VOLUNTEERS WITH DISK

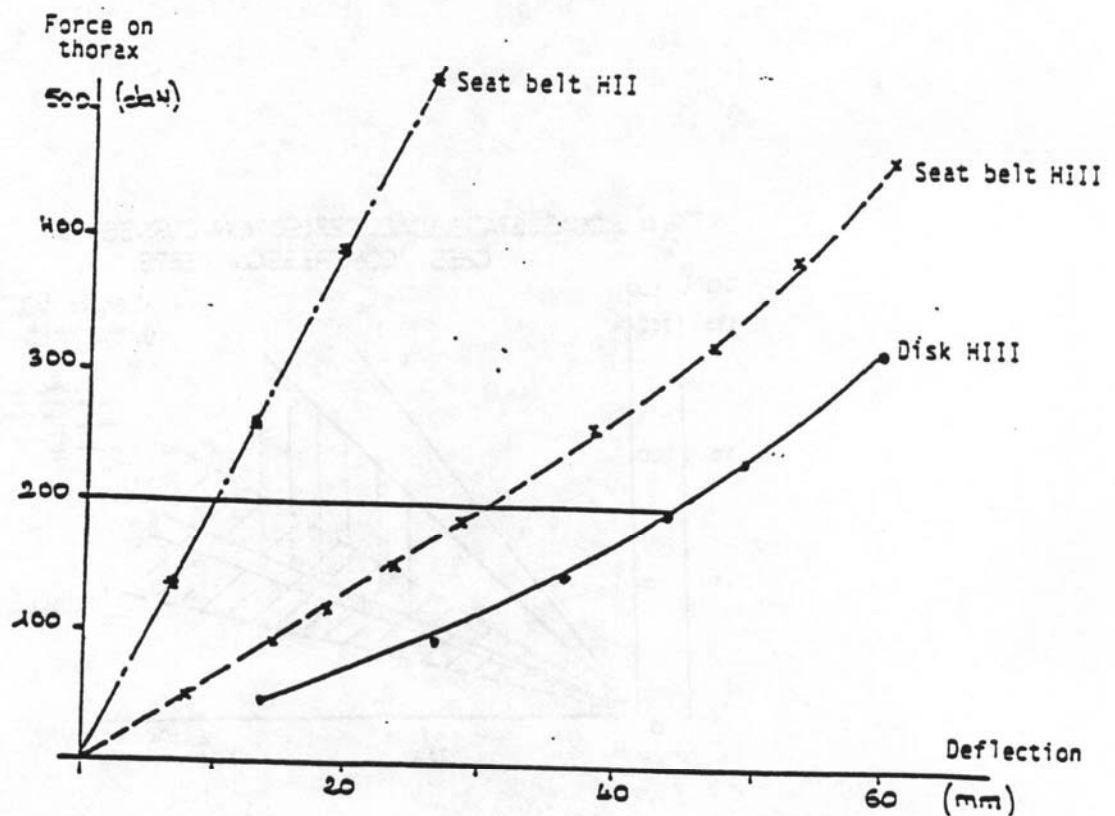
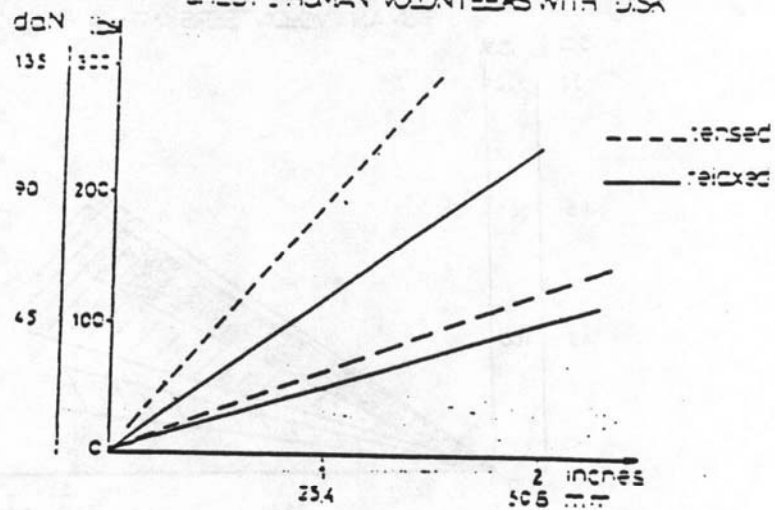


Figure 6. Hybrid III thoracic static-force-deflection characteristics under seat belt or disk loading (APR data 1988)

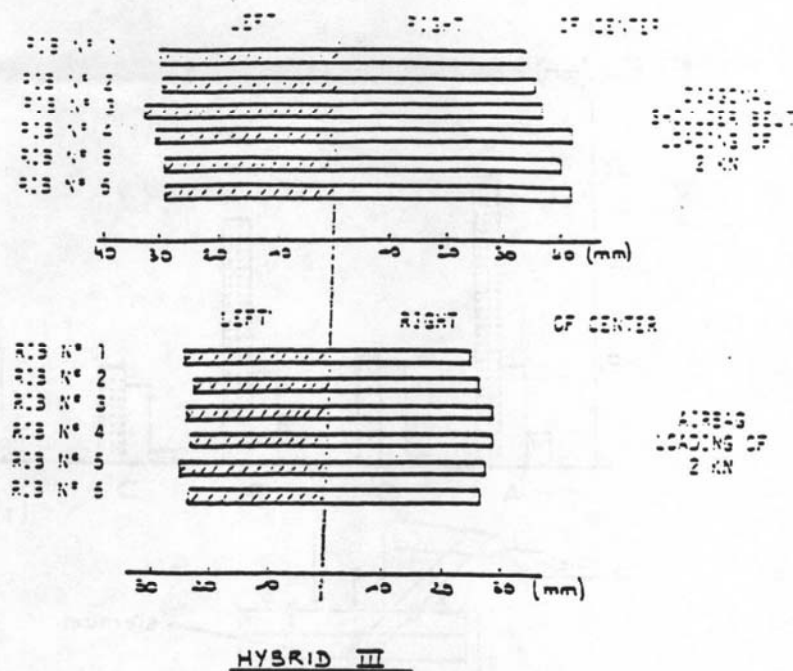


Figure 7. Deflection of ribcage due to different restraint systems in static tests (reproduced from reference 2)

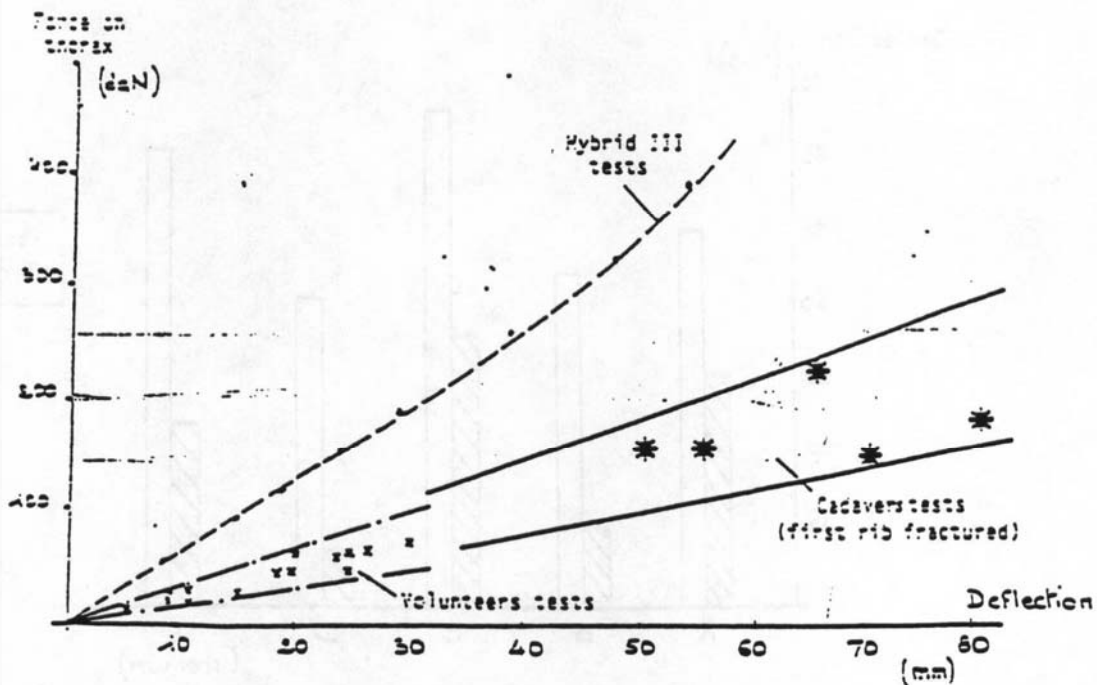


Figure 2. Thoracic Force-Deflection characteristics in static tests involving the HIII, compared to volunteer and cadaver data (AFR data 1955)

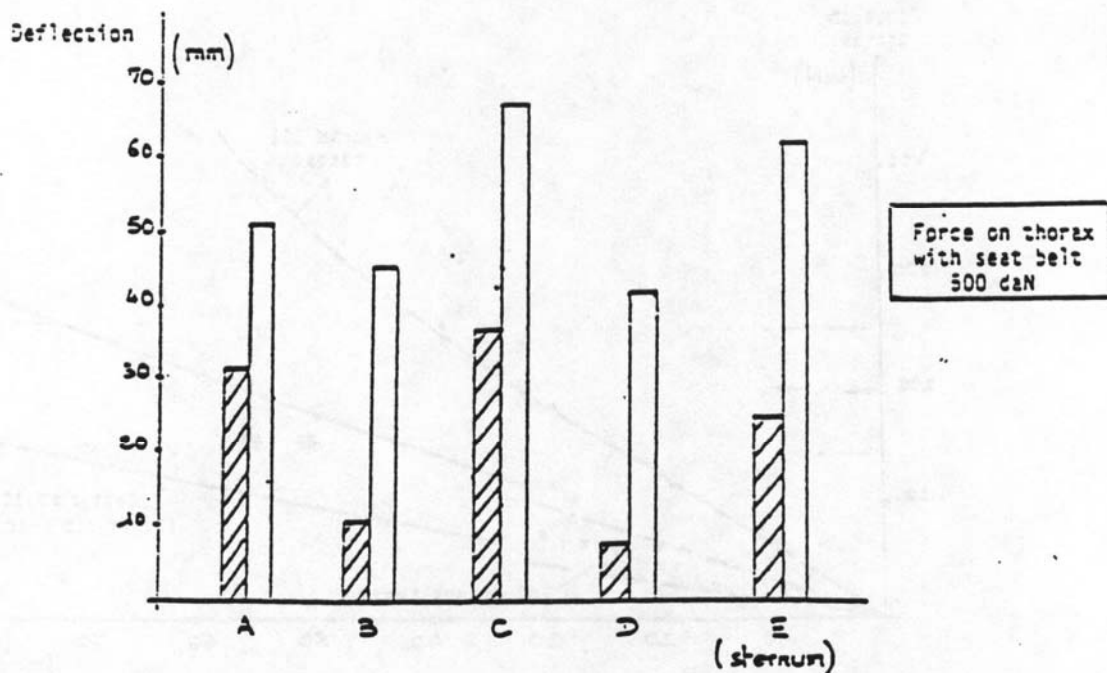
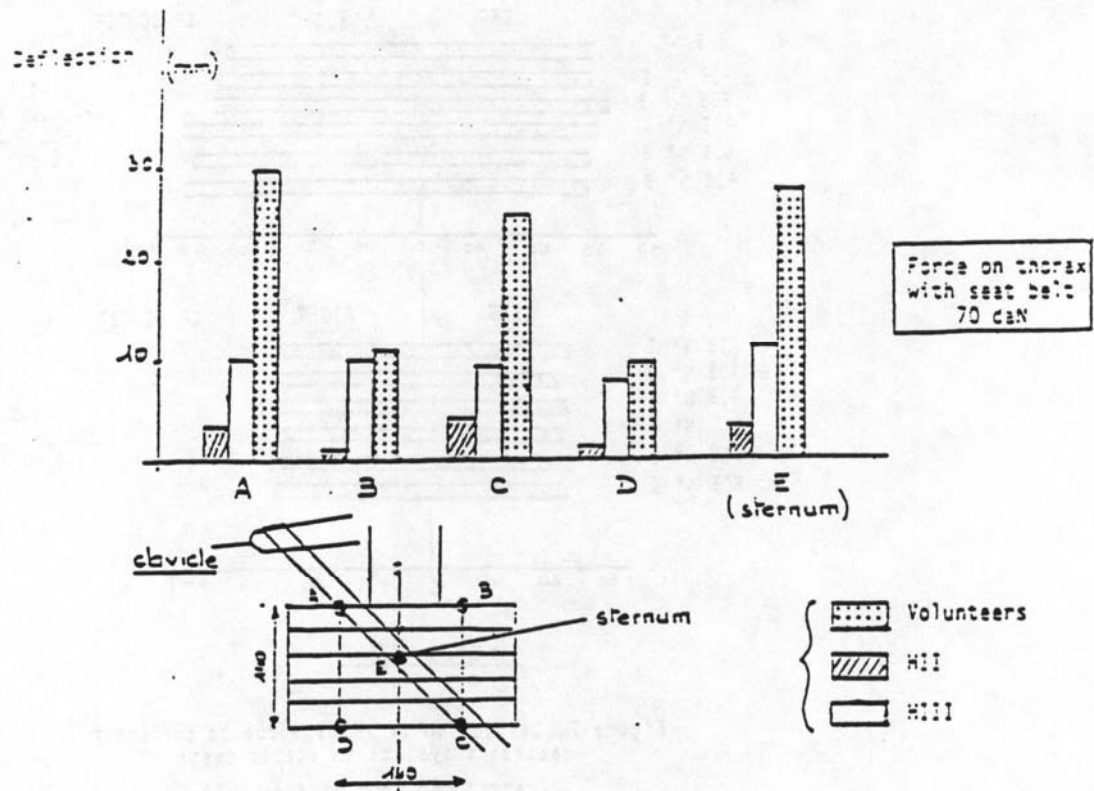


Figure 9. Chest deflection distribution as a function of loading location in static tests involving volunteers, HII and HIII dummies

(APR data 1988)

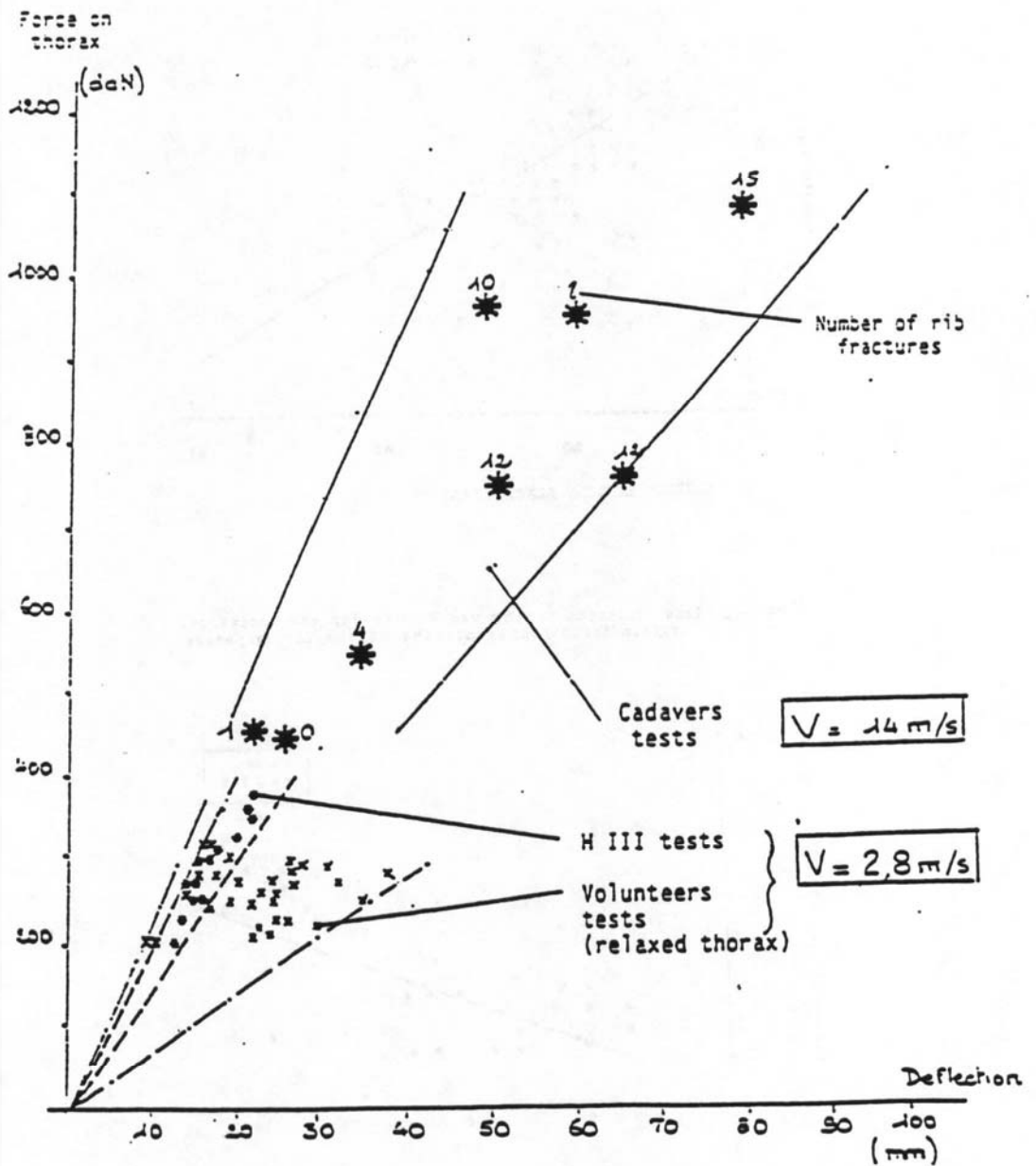


Figure 10. Thoracic Load-Deflection relationship dynamical tests, with seat belt, involving volunteers cadavers and the HIII dummy

(reproduced from ref. 3 and APR data 1988)

Fig 41A: Bone condition versus maximum force
prior to capture
Static bending tests:

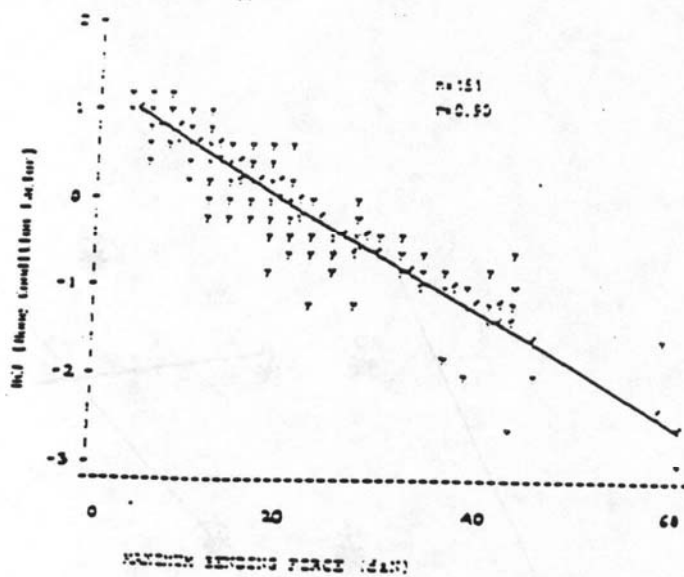
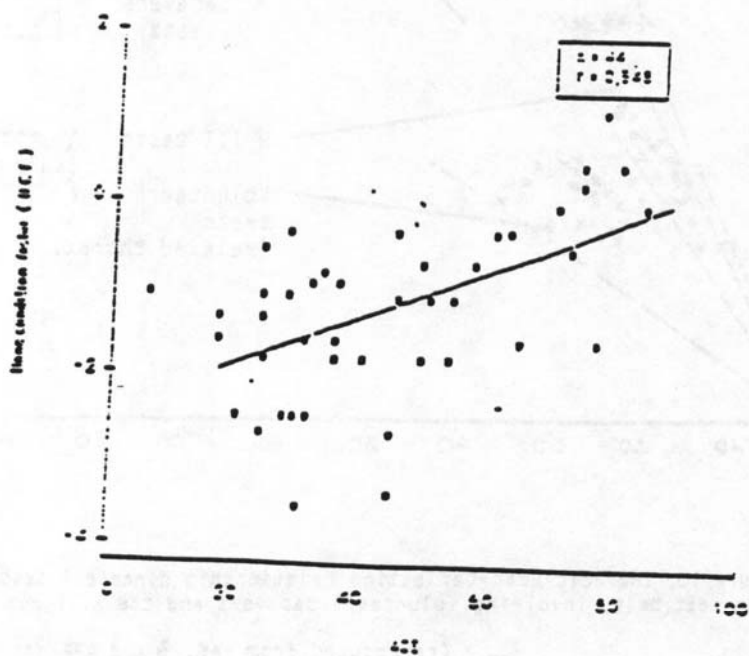


Fig 41B: Bone Condition Factor versus Age for the individual's
sudden death representative of the living people



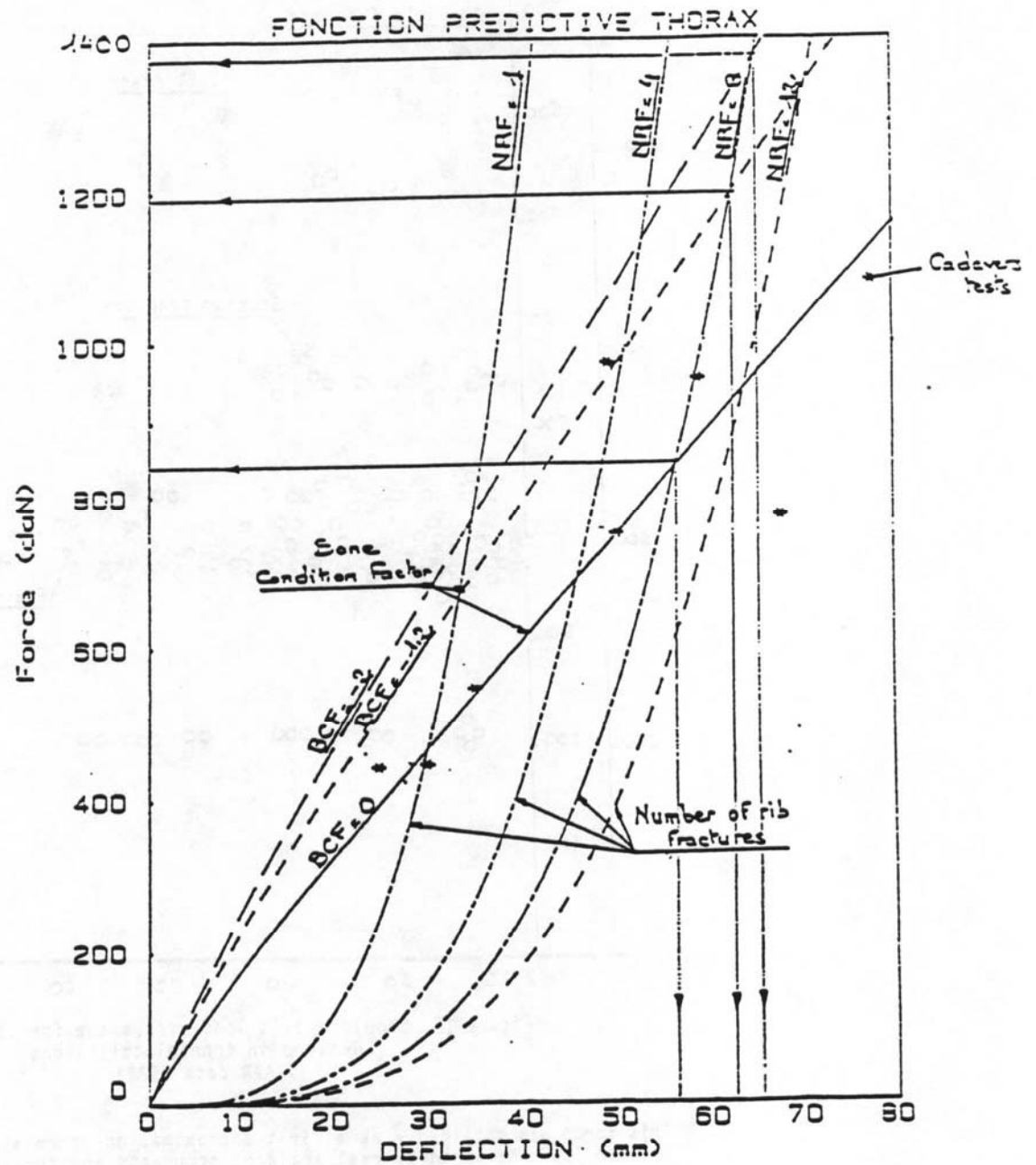


Figure 12.

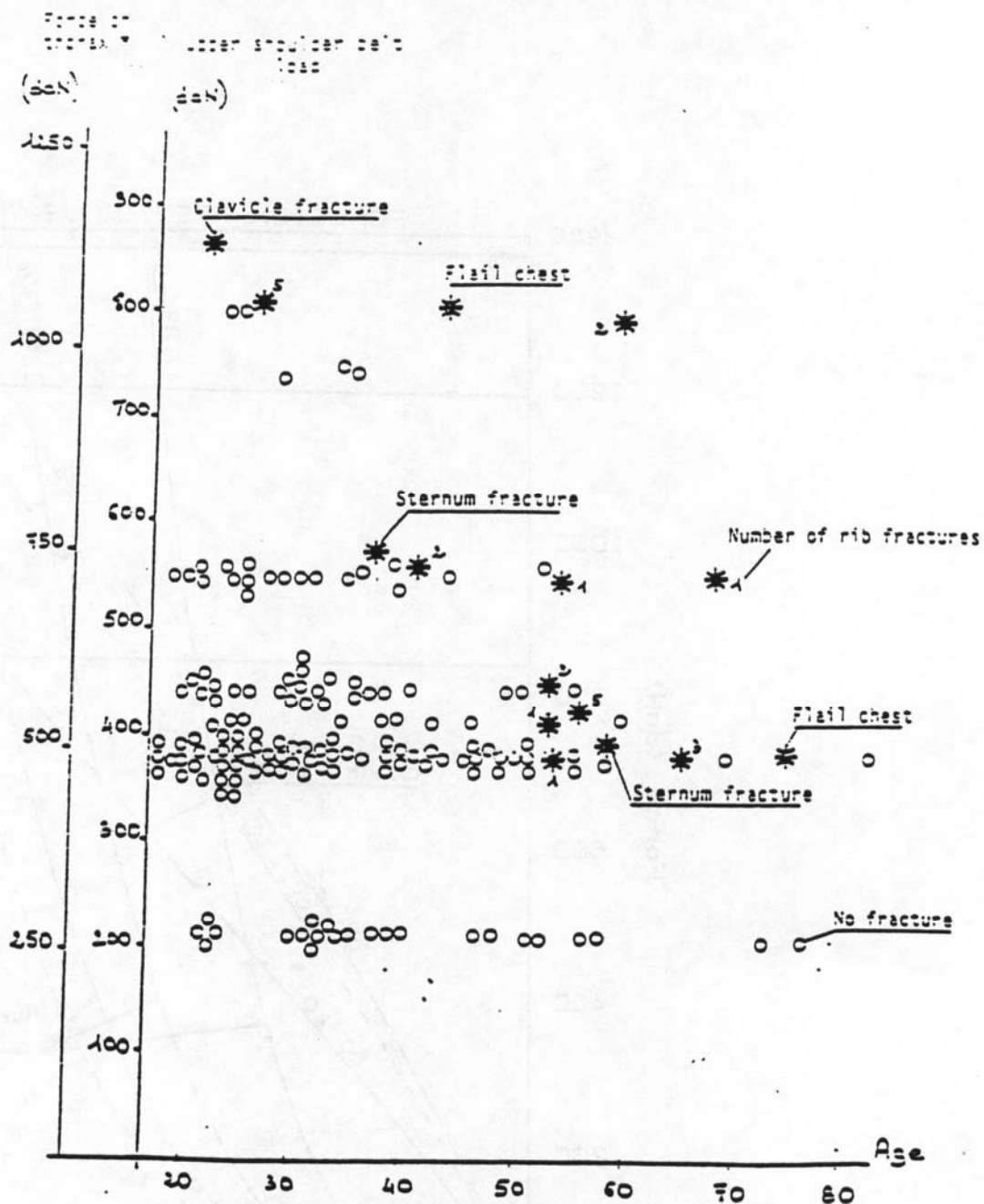


Figure 13. Shoulder belt load versus age for 166 occupants involved in frontal collisions (APR data 1988)

* This force was obtained - as a first approximation - from an analogical approach between load sustained by real accident occupants and those from experimental dummy or cadaver data, where such a force is defined as a resultant force of the lower and upper diagonal belt load.

Conclusions

1. Occupant Protection

Age of Target Population



Deflection Criterion

2. The proposed way to define this

Age of T.P.



B.C.F



Rib Fractures



Deflection Criterion

3. Reg. Analysis

$$F_{th.} = f [BCF; Deflection]$$

$$NRB = f' [BCF; Deflection]$$

Should be confirmed

4. Hybrid III

- Stiff Behaviour
- Needs Improvements

5. Future Work

- Sled Tests with young H.S.
- Duplication of APR Acc. Data
- Tests with Hybrid III

DISCUSSION

PAPER: Chest Deflection in Frontal Impact on Volunteers, Cadavers, and Dummies

SPEAKER: Farid Bendjellal, Association of Peugeot Renault

Q: Jeff Marcus, NHTSA

Do you have any idea what the area of contact was in the test that you did with the disk and the test with the belt?

A: Bendjellal

I think, the diameter of the disk was three inches but I'm not sure. I'd have to check it.

Q: Do you have any idea of what it was with the belt?

A: You mean the belt location? Could you repeat your question please?

Q: Do you have any measurement of what the contact area was with the chest when you did the test with the belt?

Q: With the belt or with the disk?

A: With either.

A: Yes, the position of the belt path was through the second rib, the fourth, the sternum and the sixth rib. From the surface of the belt we can calculate the surface, but I can't give you a figure.

Q: John Cavanaugh, Wayne State University

One of the first curves was a forced deflection curve for static loading for Hybrid III and cadaver. Were those all with skin or skin covering?

A: Yes. In these tests, as far as the Hybrid III is concerned, we performed the test with only the rib cage, without the skin.

Q: Joe Bulser, General Motors

There's a lot of work being done on static rib testing on the Hybrid III, and the rib cage is a dynamic device. It was designed to be a dynamic device and I don't understand all the extra work being done on it as a static device when it really isn't one. Can you enlighten me?

A: Your question is, in fact, why we perform static tests, with a dynamic tool like the Hybrid III and what the hard philosophy is of this work. The first step was to try and understand, in mechanical terms, the behavior of the Hybrid III rib cage and static loading.

Furthermore, to compare this situation in two loading types, the disk and the belt. However, the target is really to perform with the Hybrid III in a dynamic test, including the duplication of APR accident data as I presented, where the force of the belt, on this accident data was known. We attempted to duplicate this test and measure the force; belt force, upper and lower, as well as the Hybrid III deflection and then we will see.

Q: One other question. Was the Hybrid III stiffer with the belt system or was it softer? I'm not really sure. I suspect with the belt going across the shoulder there is a considerable amount of load on the shoulder which isn't accounted for when you're doing your static belt testing? Do you understand what I am referring to?

A: No.

Q: When you're pulling on the chest with the belt are you looking at the loads going into the shoulder?

A: Yes. We are measuring the shoulder force and also the lower force. With the two forces we can calculate the resistance of the maximum force applied to the Hybrid III of the subject at that moment with the maximum deflection.